

**UDC 621.391.81
621.3.095.13:
621.3.095.11**



RESEARCH DEPARTMENT



REPORT

**Band II f.m. sound broadcasting:
Field tests at Radio Nottingham using mixed polarisation**

No. 1970/35

RESEARCH DEPARTMENT

**BAND II F.M. SOUND BROADCASTING:
FIELD TESTS AT RADIO NOTTINGHAM USING MIXED POLARISATION**

Research Department Report No. **1970/35**

UDC 621.391.81
621.3.095.13:
621.3.095.11

This Report may not be reproduced in any form without the written permission of the British Broadcasting Corporation

It uses SI units in accordance with B.S. document PD 5686

Work covered by this report was undertaken by BBC Research Department for the BBC and the ITA
--

J.G. Spencer



Head of Research Department

BAND II F.M. SOUND BROADCASTING: FIELD TESTS AT RADIO NOTTINGHAM USING MIXED POLARISATION

Section	Title	Page
	Summary	1
1.	Introduction	1
2.	The tests	1
	2.1. The transmission	1
	2.2. Limits of accuracy of measurements	2
3.	Programme of measurements with horizontal and right-hand circular polarisation	2
	3.1. Field strength at 10 m above ground level	2
	3.2. Height gain	2
	3.3. Car radio reception	2
	3.4. Multipath propagation	3
	3.5. Home reception questionnaires	3
4.	Results of measurements with horizontal and right-hand circular polarisation	3
	4.1. Field strength at 10 m above ground level	3
	4.2. Height gain	3
	4.3. Car radio reception	3
	4.4. Multipath propagation	4
	4.5. Home reception questionnaires	4
5.	Discussion of right-hand circular polarisation	4
	5.1. Reception in the home	4
	5.2. Car radio reception	5
	5.3. Reception in the open air with portable receivers	5
6.	Measurements with four types of mixed polarisation	5
	6.1. Measurements of field strength at 10 m a.g.l.	5
	6.2. Car radio reception tests	8
7.	Conclusions	8
8.	References	9
9.	Appendix	9

© BBC 2003. All rights reserved. Except as provided below, no part of this document may be reproduced in any material form (including photocopying or storing it in any medium by electronic means) without the prior written permission of BBC Research & Development except in accordance with the provisions of the (UK) Copyright, Designs and Patents Act 1988.

The BBC grants permission to individuals and organisations to make copies of the entire document (including this copyright notice) for their own internal use. No copies of this document may be published, distributed or made available to third parties whether by paper, electronic or other means without the BBC's prior written permission. Where necessary, third parties should be directed to the relevant page on BBC's website at <http://www.bbc.co.uk/rd/pubs/> for a copy of this document.

BAND II F.M. SOUND BROADCASTING: FIELD TESTS AT RADIO NOTTINGHAM USING MIXED POLARISATION

Summary

Field tests have been carried out in the Nottingham area to investigate the effects of a change from horizontal to either circular or slant polarisation for Band II f.m. sound transmissions.

The results show that there is little to choose between these two types of mixed polarisation from the point of view of reception. A change to either would be equivalent to a reduction of transmitter power of about 3 dB for listeners using efficient aerials at roof level but would produce a negligibly small effect on reception indoors with portable receivers or receivers using built-in or room aerials. For reception outdoors with car radio or portable receivers the change would be, on average, equivalent to an increase in transmitter power of 6 dB and 9 dB respectively but would vary considerably from one receiving site to another.

These results apply to the case where the total effective radiated power is the same irrespective of the type of polarisation. They show good agreement with the measurements made in earlier tests of circular polarisation in the area of Kingswood, Surrey.

1. Introduction

In 1968, an investigation was carried out in the area around Kingswood, Surrey, to examine the effects on radio reception in Band II of a change from horizontal polarisation (h.p.) to circular polarisation (c.p.) of the transmissions.¹ The results of any such investigation are partly dependent on the type of terrain and surface features of the area concerned and it is obviously desirable to examine more than one area. Furthermore, a decision to adopt a different type of polarisation where practicable is first being considered in respect of Local Radio stations. It was therefore decided to carry out a similar investigation at Nottingham, using the Nottingham Local Radio transmitter for the purpose, and to extend the investigation to cover slant polarisation.

2. The tests

2.1. The transmission

The transmitter and aerial were modified to permit radiation of horizontal, right-hand circular, left-hand circular, +45° slant or -45° slant polarisation. Due to limitations of time, a full series of tests was made only with horizontal and right-hand circular polarisation. A further limited series of tests was carried out with the four types of mixed polarisation.

As in the Kingswood tests, the case investigated was that in which the total effective radiated power (e.r.p.) on mixed polarisation is the same as that on h.p., i.e. the e.r.p. of the h.p. transmission used as the reference is equal to the sum of the e.r.p.s of the h.p. and v.p. components of the mixed polarisation transmission.

The four types of mixed polarisation are identified as follows from the point of view of an observer standing with his back to the transmitting aerial and looking in the direction of propagation:

Right-hand circular polarisation (r.c.p.) : the field vector rotates in a clockwise direction.

Left-hand circular polarisation (l.c.p.) : the field vector rotates in an anticlockwise direction.

+45° slant polarisation (+45°) : the electric field vector is inclined at an angle 45° clockwise relative to the vertical.

-45° slant polarisation (-45°) : the electric field vector is inclined at an angle 45° anticlockwise relative to the vertical.

The above definitions of circular polarisation are in accordance with the I.R.E. Standards on Wave Propagation (1950).² To the best of the author's knowledge, no generally-accepted definitions of slant polarisation exist and the above are put forward to define the conditions that were investigated in the work covered by this report.

2.2. Limits of accuracy of measurements

The original transmitting aerial at Nottingham consisted of four tiers of square loop arrays producing a horizontally polarised field. To convert this array for radiating mixed polarisation, a vertical unipole with simulated ground plane was added to provide the vertically polarised component. Since the gain of the h.p. and v.p. aerials differed, the requirement for equal amplitude h.p. and v.p. components was met by using additional power amplifiers and unequal power division between the two aerials.

Because the h.p. and v.p. aerials were at slightly different heights and had different vertical radiation patterns, it was not possible to check the mixed polarisation transmissions at points very close to the transmitting array. The system was therefore set up by adjusting the amplitudes and relative phases of the feed currents to the h.p. and v.p. transmitting aerials to produce the appropriate types of polarisation at a test site approximately 6.2 km from the transmitter in a south-easterly direction where the intervening terrain was as flat and unobstructed as possible. Check measurements were made at two additional sites 6.5 km south and 4.8 km south-south-east of the transmitter.

The great majority of the reception measurements were made at sites in a sector lying between west and north from the transmitter, this being the area enclosing the densely-built city centre and more heavily-populated suburban districts. It became evident during the course of the experiment that, due to asymmetries in the transmitting aerial system, the type of polarisation radiated in the north-western sector was not identical with that radiated in the south-eastern sector in which the transmission check sites were situated.

As far as right-hand circular polarisation was concerned, the errors appeared to consist of a decrease in the magnitude of the h.p. component of between 1 dB and 2 dB and a shift of the relative phase of the h.p. and v.p. components such as to produce slightly elliptical polarisation with the major axis at about 20° to the vertical.* Since the magnitude of these errors had to be deduced partly from the reception measurements, which were subject to the effects of propagation and local reflections, it is not possible to be more precise. They are not considered sufficiently large materially to affect the validity of the conclusions drawn, particularly in respect of reception by car radio and portable receivers in the open air. Previous measurements¹ indicate that in these cases the improvement brought about by the use of mixed polarisation is due chiefly to the transmission of a v.p. component. There was no evidence at Nottingham that the transmitted v.p. component was significantly in error.

* This was believed to be caused mainly by an additional h.p. component of radiation resulting from excitation of the nominally v.p. aerial rather than by any significant non-uniformity in the radiation pattern of the h.p. aerial itself.

The aberrations of the transmitting aerial and their effects on other types of mixed polarisation are discussed more fully in Section 6.1.

3. Programme of measurements with horizontal and right-hand circular polarisation

3.1. Field strength at 10 m above ground level

In this and following sections of this note, the components of the field are referred to as HP/H, HP/V, CP/H and CP/V. The two letters preceding the solidus define the type of transmission and the last letter the component of the received field, either horizontal or vertical.

Measurements were made of HP/H, HP/V, CP/H and CP/V at 10 m above ground level (a.g.l.), using a single dipole as the receiving aerial, at 242 sites.

3.2. Height gain

Measurements of HP/H, HP/V, CP/H and CP/V at heights of 10 m, 5 m, 2.5 m, 0.9 m and 0.3 m a.g.l. were made at 40 sites with the measuring aerial above the road surface. At 14 of these road sites, an additional series of measurements at 2.5 m, 0.9 m and 0.3 m a.g.l. was made at a point adjacent to the road site but on adjoining park or meadow-land.

The purpose of these latter measurements was to ascertain whether there was a significant difference between the height gain over open land and that over a road surface.

3.3. Car radio reception

Continuous recordings of the aerial output voltage with both h.p. and r.c.p. transmission were made on four cars with wing-mounted rod aerials over four routes running approximately 15 km north, 6 km east, 6 km south and 6 km north-west from the city centre. The cars used were a Ford Cortina saloon, a Ford Escort saloon, an Austin A60 shooting brake and a Triumph Herald convertible. Each route was traversed twice in each direction by each car. These measurements were repeated with the Ford Cortina using a near-vertical rod aerial mounted on the roof gutter.

Similar measurements were made over four out-lying circular routes, mainly over high ground, at distances of between 18 km and 27 km from the transmitter. The Cortina was used for three of these runs and the Austin for the remaining one. Both cars used their wing-mounted aerials and in every case the route was traversed once only.

A subjective assessment of the grade of car radio reception obtained with both h.p. and r.c.p. transmission was made over a route running approximately north and south through the city centre to a distance of some 20 km to the north and 30 km to the south. This route was traversed once in each direction, both

with h.p. and r.c.p. transmission, using the Austin A60 shooting brake equipped with a car radio receiver of German manufacture, and the procedure repeated using the Ford Escort with a British car radio receiver.

3.4. Multipath propagation

Measurements were made, using a receiver specially designed for the measurement of multipath propagation³ at 11 sites. The sites were selected, by examination of the ground profiles of the propagation paths and local observation of potential shadowing objects, as being likely to be subject to multipath effects.

3.5. Home reception questionnaires

Broadcast announcements were made by Radio Nottingham that certain tests (unspecified) were being made in connection with their transmissions and inviting the public to participate by writing in for and completing a questionnaire.

4. Results of measurements with horizontal and right-hand circular polarisation

4.1. Field strength at 10 m above ground level

The results of the 10m field-strength measurements are given in Table 1 in terms of the mean levels of HP/V, CP/H and CP/V relative to that of HP/H. The sites have been subdivided into zones according to their distance from the transmitter. The 0 to 5 km zone corresponds roughly to the densely-built city area, 5 to 10 km the suburbs and rural outskirts, while beyond 10 km is countryside and the small surrounding towns such as Ilkeston and Hucknall.

TABLE 1
Mean field strength relative to HP/H at
10 m a.g.l., dB

Zone	HP/V	CP/H	CP/V	Total Number of Sites
0 — 5 km	-18.4	-4.3	-2.7	71
5 — 10 km	-20.6	-4.3	-1.4	40
10 — 15 km	-21.4	-3.9	-0.5	70
> 15 km	-23.2	-4.2	-0.9	61
All sites	-20.9	-4.2	-1.4	242

The mean level of HP/V indicates that, in general, little re-polarisation* of the h.p. transmission occurs

* Re-polarisation is the conversion of some of the signal power into a component whose plane of polarisation is orthogonal to that of the transmission.

at a height of 10 m. As might be expected, more re-polarisation occurs in the densely built-up area.

The mean relative level of CP/H should ideally be -3 dB. In view of the aberrations of the transmitting aerial mentioned in Section 2.2., the measured level of -4.2 dB is most probably due to the fact that the radiated h.p. component in the north-west quadrant was smaller than it should have been during r.c.p. transmission.

Extensive measurements in the U.K. over a long period have not revealed any great difference between h.p. and v.p. at v.h.f. in terms of the field strength produced at 10 m a.g.l., taking all types of terrain into account. The relative level of CP/V in Table 1 would therefore be expected to be about -3 dB. It is in fact slightly higher than this, also there is a small but systematic rise in relative level with increasing distance, at least out to the 10–15 km zone.

4.2. Height gain

The results of the height gain measurements are given in Table 2. This shows the mean values for all 40 road sites, normalised to the mean value of HP/H at 10 m a.g.l.

TABLE 2
Mean relative field strength variation
with height, dB

Height m a.g.l.	HP/H	HP/V	CP/H	CP/V
10	0	-21.2	-4.9	-2.3
5	-6.2	-23.2	-11.0	-8.2
2.5	-10.4	-29.4	-14.9	-13.6
0.9	-19.3	-30.9	-22.5	-16.8
0.3	-26.9	-29.3	-28.4	-14.8

The measurements of height gain made in parks and meadow-land do not reveal any significant differences from those made at the road sites.

4.3. Car radio reception

The results of the car aerial output voltage measurements are summarised in Table 3. The figures quoted are the ratios of the values of the output voltage that are exceeded with the two types of transmission for 10%, 50% and 90% of the total distance travelled, *not* the value of voltage ratio that is exceeded for that percentage of the distance. The routes classified 'inner' are those radiating out from the city centre which were, for the most part, within built-up areas. Those classified as 'outer' are those between 18 km and 27 km from the city centre, covering generally high, rural country.

TABLE 3

Car radio reception: Mean ratio of aerial output voltage with
c.p. transmission to that with h.p. transmission dB

Car	Routes	Aerial	Ratio of 10% voltages	Ratio of 50% voltages	Ratio of 90% voltages
Austin A60	Inner	Wing	7.1	6.6	6.2
Cortina	Inner	Wing	3.6	4.4	4.3
Escort	Inner	Wing	6.2	5.2	5.0
Herald	Inner	Wing	7.0	8.2	8.3
Cortina	Inner	Roof	7.8	7.4	7.0
Austin and Cortina	Outer	Wing	6.1	6.3	6.0
Overall average			6.3	6.3	6.1

The subjective assessment of car radio reception was made by grading the impairment of service along the route, caused by noise, ignition interference and drop-outs, with one type of polarisation, repeating the experiment on the following day with the other type of polarisation, and comparing the gradings point by point along the route.* The overall grade of service was judged to be some 1 to 1½ grades better with r.c.p. transmission than with h.p. transmission, taking the average of the assessments over the whole of the test route. It should be emphasised that an assessment made in this way can be regarded as only very approximate, since the subjective judgement of signal-to-noise ratio is greatly affected by traffic conditions and the type of programme material.

It was noted during the course of the journeys undertaken for the subjective assessment that the advantage of r.c.p. was more marked at greater distances from the transmitter. For example, towards the southern end of the route, using the Austin car with the German receiver, the h.p. transmission became totally unusable at about 24 km from the transmitter. Reception of r.c.p. however, was still acceptable for casual listening (grade 3 to 4) at the end of the run at a distance of about 32 km.

4.4. Multipath propagation

None of the sites examined showed serious multipath effects although there was some indication that on the average, the r.c.p. transmission was slightly more prone to multipath disturbances than was h.p. The results obtained in this part of the investigation must be regarded as inconclusive.

* The grading scale used was the 6-point impairment scale:

- Grade 1 – Imperceptible
- Grade 2 – Just perceptible
- Grade 3 – Definitely perceptible but not disturbing
- Grade 4 – Somewhat objectionable
- Grade 5 – Definitely objectionable
- Grade 6 – Unusable

4.5. Home reception questionnaires

The public response to the invitation to co-operate in the tests was disappointing. A total of 39 questionnaires was received and of these only 27 contained information in an analysable form.

Sixteen of these questionnaires referred to portable receivers with built-in aerials. These showed no significant difference between reception with r.c.p. or with h.p. transmission.

The remaining 11 questionnaires referred to table model and console receivers with various types of aerials, and one portable using an outdoor aerial at roof level. These showed an average degradation of about 0.3 of a grade when receiving r.c.p. as compared with h.p. The total number of analysable questionnaires was rather small, so that this difference is barely significant.

5. Discussion of right-hand circular polarisation

5.1. Reception in the home

The results of the listener questionnaires, given in Section 4.5., indicate that reception in the home with portable receivers is not significantly affected by a change of transmission from h.p. to r.c.p. This confirms the results obtained in the more comprehensive tests of home reception carried out in 1968.¹

The questionnaire results for home reception with table model and console receivers, with either external or internal aerials, indicating that reception with r.c.p. transmission has a mean grade 0.3 worse than with h.p. transmission, in fact show about the amount of degradation that would be expected for those listeners who suffered most from the change, i.e. those with roof aerials at the fringe of the service area. The average degradation, taking into

account listeners with an adequate field strength from both h.p. and r.c.p. and those with room aerials, would be expected to be less than 0.3 of a grade. However, in view of the small size of the sample and the small amount of degradation reported, this result is not regarded as conflicting significantly with the objective measurements or with the results obtained in the 1968 tests.¹

5.2. Car radio reception

The objective measurements of car-aerial output voltages given in Section 3.4. show an average advantage to c.p. of about 6 dB. This is in close agreement with the result of 7 dB predicted from the analytical measurements made during the 1968 tests.¹

The subjectively assessed improvement in reception resulting from the change from h.p. to r.c.p., taking the average over the whole test route, was slightly more than one grade. This agrees fairly well with the objectively measured improvement of 6 dB, bearing in mind the approximate nature of the subjective assessment. The larger subjective benefit of c.p. at greater distances, referred to in Section 4.3., appears rather surprising in view of the modest increase in aerial terminal voltage shown in the objective measurements made at the outlying test routes. The explanation may lie in the very non-linear relationship between the input and output signal-to-noise ratios of a f.m. system in the region of improvement threshold.

5.3. Reception in the open air with portable receivers

The relative merit of h.p. and r.c.p. transmission from the point of view of reception by portable receivers in the open air can be assessed by comparing the magnitude of the vertically polarised component of field which each type of transmission produces at the height at which the portable receiver is situated, assumed here to be 0.3 m. It is in this parameter that the results obtained at Nottingham differ most markedly from those obtained at Kingswood. The mean ratio of CP/V to HP/V at 0.3 m a.g.l. measured at Kingswood was 5.5 dB while at Nottingham it was 14.5 dB at the road sites and 12.5 dB at the open land sites.

This difference is probably due in large part to the different type of terrain. The Kingswood district is generally quite heavily wooded with many tall trees and areas of heathland covered with scrub. The country also undulates quite sharply with frequent steep hills. This type of countryside appears to produce extensive re-polarisation of the wave travelling over it at low heights and thus considerably reduces the advantage below that expected in theory for circular polarisation over flat ground. The Kingswood transmitting aerial was also at a height comparable with that of large trees in the vicinity so that some re-polarisation could have been occurring locally.

The Nottingham district is generally much flatter with few trees to break the surface of the open fields which cover much of the area. Furthermore, the transmitting aerial, on a mast 42 m high situated on a site 92 m a.m.s.l. stood well above any local obstructions and gave a line-of-sight propagation path to much of the area investigated.

The situations in which open-air reception is likely to be of interest to listeners are probably nearer to the Kingswood type of countryside than to the Nottingham type, i.e. in woodland, heathland or on low-lying beaches screened by terrain. It is therefore suggested that, while the assessment of the benefit of c.p. in the 'picnic' situation made from the Kingswood tests may be slightly underestimated at 5 to 6 dB, it is unlikely to be greatly in error. Perhaps 8 to 10 dB would be a fair estimate for the average case.

6. Measurements with four types of mixed polarisation

A shorter series of measurements was arranged to compare the four types of mixed polarisation, r.c.p., l.c.p., $+45^\circ$ and -45° .

Slant polarisation offers, in theory, an advantage over circular polarisation in that listeners with receiving aerials arranged for horizontal polarisation can recover the 3 dB loss of signal by tilting their aerials through 45° . The object of the tests was to find to what extent this advantage would be obtainable in practice and also to see whether the four types of mixed polarisation were of equal merit from the point of view of car radio reception.

6.1. Measurements of field strength at 10 m a.g.l.

To assess the effects for listeners with aerials at roof height, the polarisation of the received signal was measured at 51 sites by rotating the receiving aerial in the vertical plane and recording the field strength as a function of the vertical angle. The results are shown in Table 4 and Fig. 1. The 'level of maximum' shown in the table is the maximum value of the field strength measured at any angle of the receiving aerial. The angle of polarisation quoted in Fig. 1 is relative to the vertical; positive angles represent clockwise rotation from the point of view of an observer facing the receiving aerial with his back to the transmitter.

If each type of polarisation transmitted were correct, and were perfectly preserved at the receiving sites, the h.p. and v.p. components of the received signal would be equal and the ratio of the maximum to the h.p. component would be 3 dB for slant polarisation and unity for circular polarisation. It can be seen from Table 4 that the -45° transmission gives results very close to the ideal. Furthermore, as shown

In Fig. 1(b), the variation of the angle of polarisation from site to site is very small, 80% of sites being between -30° and -50° .

The results for $+45^\circ$ polarisation differed so strikingly from those for -45° that further investigation was obviously required. All of the 51 sites originally measured lay on bearings between 242°

and 352° from the transmitter, i.e. in the opposite sector from that in which the transmission checks were made. Further measurements were therefore made of the $+45^\circ$ and -45° conditions at 14 sites in the south to east sector. Histograms showing the angles of polarisation at these sites are given in Fig. 1(c) and (d).

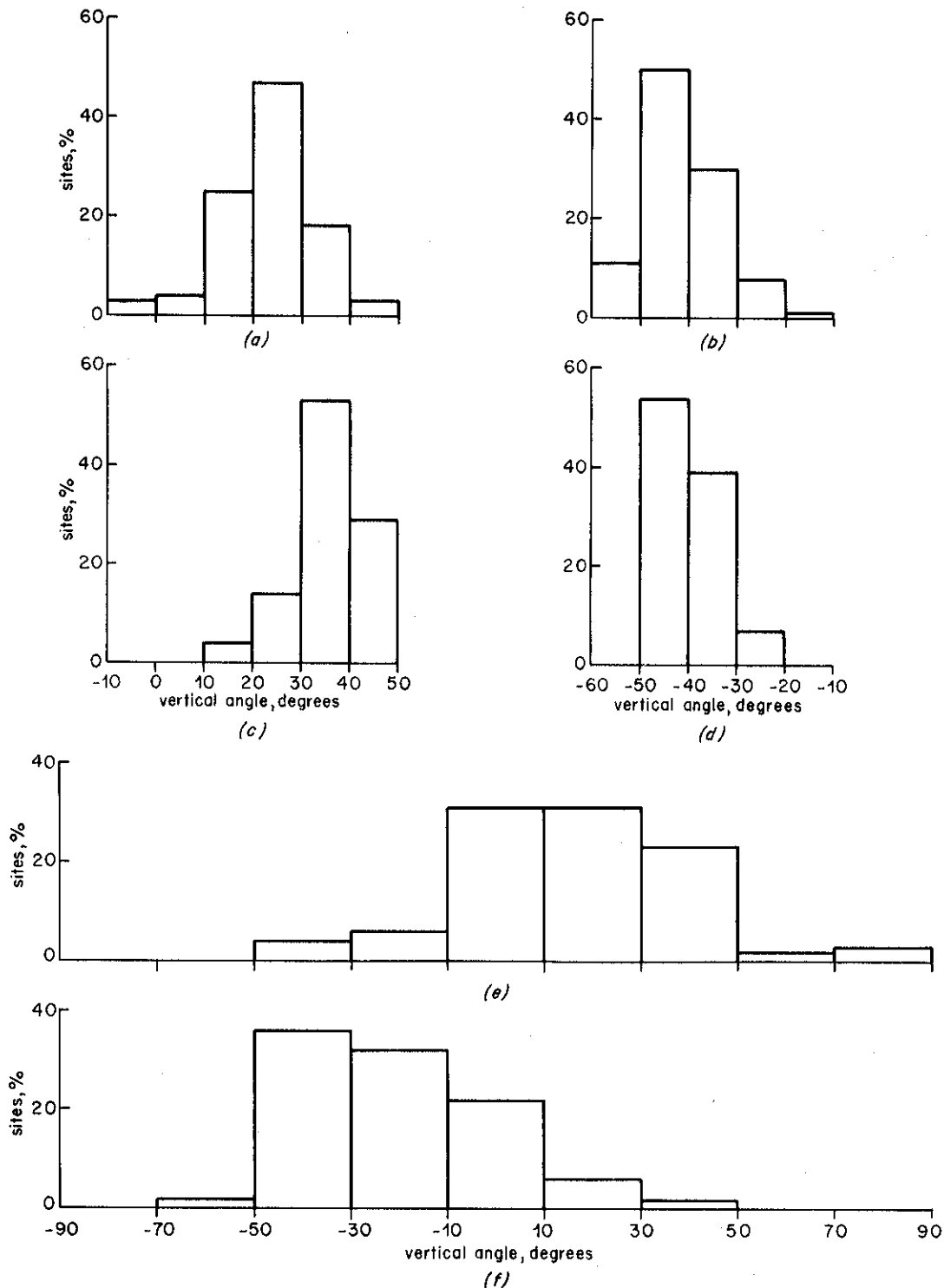


Fig. 1 — Angle of receiving aerial, relative to vertical, for maximum signal, with different transmitted polarisations

(a) $+45^\circ$. 51 sites in NW sector (b) -45° . 51 sites in NW sector (c) $+45^\circ$. 14 sites in SE sector
(d) -45° . 14 sites in SE sector (e) RCP. 51 sites in NW sector (f) LCP. 51 sites in NW sector

TABLE 4
Mean field strength at 10 m a.g.l. (51 sites)

	Type of polarisation			
	+45°	-45°	RCP	LCP
Level of h.p. component, dB(μ V/m)	56.1	62.7	61.7	61.7
Level of v.p. component, dB(μ V/m)	63.8	63.5	64.0	64.4
Level of maximum component, dB(μ V/m)	64.6	65.9	64.5	65.1
Ratio of maximum to minimum value, dB	20.1	15.8	4.0	4.9
Ratio of maximum value to h.p. component, dB	8.5	3.2	2.8	3.4
Ratio of v.p. to h.p. component, dB	7.7	0.8	2.3	2.7

Comparing Fig. 1(b) and 1(d) shows that the transmitting aerial characteristics were sensibly the same in both sectors for the -45° condition. From Figs. 1(a) and 1(c), and Table 4, however, it is apparent that the h.p. component radiated on +45° polarisation in the north-west sector was heavily attenuated, resulting in a shift of the angle of polarisation to about +25°.

The histograms for the two types of circular polarisation, Fig. 1(e) and (f), show a significant grouping of the majority of results, for r.c.p. around 20° and for l.c.p. around -20°. This implies that the transmissions were in fact elliptically polarised at the receiving sites. The possibility was considered that this may have been caused by a systematic effect of propagation that is discussed in more detail in the Appendix. However, a fuller analysis, not presented here, of the measurements summarised in Fig. 1 did not show the variation of polarisation with distance from the transmitter that this effect would be expected to produce. It was therefore concluded that the major factor responsible was an instrumental defect in the transmitting aerial that caused elliptical polarisation to be radiated in the north-west sector. This type of elliptical polarisation would require two errors, a v.p./h.p. ratio greater than unity and a shift in the relative phase of the v.p. and h.p. components. Evidence that the h.p. component of the r.c.p. transmission was too small had already been noted in the measurements described in Section 4.1. Bearing in mind that these earlier measurements included a proportion from sites outside the north-western sector, and indicated a mean reduction in the r.c.p. h.p. component of 1.2 dB, it seems reasonable to deduce that the reduction in the north-western sector was slightly greater.

Summarising the foregoing, it was expected that the required information could be extracted from the measured ratios of maximum value to h.p. component of field strength shown in Table 4. In the event, the errors in polarisation introduced by the aberrations of the transmitting aerial obscured the comparatively small differences between the various

types of polarisation that were expected. However, it is possible to obtain the required information from the various measurement results shown in Table 4 and Fig. 1.

Considering the two forms of slant polarisation, the ratio of maximum to minimum values of field strength show that the average received signal was polarised in the form of a narrow ellipse with a ratio of major to minor axes of some 16 dB to 20 dB. In the case of -45° polarisation, the angle of polarisation measured at the receiving sites varied very little, more than 80% of all sites falling within a range of $\pm 10^\circ$. With nominal +45° polarisation the two groups of sites in opposite sectors were illuminated with differently polarised signals but again, within each group the angle of polarisation was very well maintained. This evidence shows that the polarisation of the nominally +45° and -45° signals in this experiment, although not accurate, was very well maintained at the receiving sites. This justifies the conclusion that, if accurately slant polarised transmission were used, the majority of listeners with aerials arranged for h.p. transmission would be able to recoup at least a large part of the 3 dB loss of signal by tilting their aerials through 45°.

In the cases of nominal circular polarisation, the mean ratio of maximum to minimum received signal shown in Table 1 is from 4 dB to 5 dB. As would be expected when the locus of the transmitted field vector is a comparatively broad ellipse, random repolarisation in propagation produces a larger spread of the apparent angle of polarisation at the receiving sites, as shown in Fig. 1(e) and (f). Had the transmission been truly circularly polarised, the effects of propagation would presumably have produced a more random distribution of the angle of maximum field at the receiving sites. Furthermore, the comparatively high average ratio of maximum value to h.p. component, viz. about 3 dB, shown in Table 4 for r.c.p. and l.c.p., is caused by the systematic ellipticity of the transmission. It would have been significantly lower had the transmitted polarisation been truly circular, but not as low as the ideal value of 0 dB because of random propagation effects. The

conclusion is, that with circularly polarised transmission, although it might in many cases be possible to obtain some increase in the received signal by rotating the receiving aerial away from the horizontal plane, the increase would be, on average, quite small and the angle of the aerial required to obtain it would be unpredictable.

6.2. Car radio reception tests

The car radio reception tests on the four types of mixed polarisation were made in the manner described in Section 3.3. by recording the output voltage from car radio aerials on runs over the four inner routes and one outer route.

The errors in the transmission that confused the field strength measurements at 10 m a.g.l. affected chiefly the h.p. component of the transmitted signal. The v.p. component, as is shown by the results in Table 4 and confirmed by other measurements made in the course of investigating the anomalous performance of the transmitting aerial but not produced in this report, was radiated at the same amplitude on all types of polarisation. Previous work on car radio reception at v.h.f. has shown that, with a mixed polarisation transmission, the v.p. component of the field makes the major contribution to the signal received on the car radio aerial. It is therefore considered that the results of these car radio tests were not materially affected by the errors in polarisation of the transmissions.

The results of the measurements are summarised in Table 5. These show slight differences in performance between the various types of polarisation on individual cars, for example the Escort appears to have rather better sensitivity to $+45^\circ$, and the Cortina poorer sensitivity to -45° . A similar effect was noted in the 1968 tests and is due to peculiarities of the geometry of the individual car and its aerial. Taken as a whole, Table 5 does not reveal any significant systematic difference between the four types of mixed polarisation.

7. Conclusions

The effect of a change from horizontal polarisation to either slant or circular polarisation for a Band II sound transmission, as far as listeners at home with efficient aerials at roof level are concerned, would be equivalent to a 3 dB reduction in the transmitted power. If slant polarisation were used, a substantial part of this loss could be recovered at most receiving sites by tilting the receiving aerial through 45° . However, unless all the Band II transmitters serving a given area were co-sited and used the same type of polarisation, this advantage could only be obtained for some transmissions at the expense of a loss of signal from others.

For car radio reception the effect of a change to either form of mixed polarisation would be equivalent, on the average, to an increase in transmitter power of about 6 dB.

For listeners with portable receivers operating close to ground level in the open air, the results of the measurements at Nottingham predict an improvement corresponding to an increase in transmitter power of about 13 dB. These particular tests were only carried out with right-hand circular polarisation but there is no reason to doubt that similar results would have been obtained in this area with any form of mixed polarisation. Earlier measurements with circular polarisation in the area around Kingswood in Surrey had shown an improvement for this type of reception of only about 6 dB and it is thought that the difference between the results of these two sets of measurements is due to the difference in the type of terrain in which they were made. Reception at v.h.f., when the receiving aerial is close to ground level, depends to a very great extent on local terrain shielding and the amount of re-polarisation of the signal that occurs. This will vary between wide limits from area to area and is impossible to predict except on a statistical basis. From the results of the two series of tests described above it appears that the average

TABLE 5

Mean car radio output voltage, dB(μ V)

Type of Polarisation	Voltage exceeded for stated % time								
	Escort			Cortina			Mean of two cars		
	10%	50%	90%	10%	50%	90%	10%	50%	90%
$+45$	51.5	40.5	33.1	46.3	35.9	29.1	48.9	38.2	31.1
-45	50.2	39.6	31.2	43.7	34.0	26.2	46.9	36.8	28.7
RCP	51.3	39.4	31.0	47.0	36.3	28.7	49.1	37.8	29.8
LCP	50.2	39.5	30.5	45.8	37.9	29.9	48.0	38.7	30.2

value of the improvement conferred by a change to mixed polarisation is about 9 dB but that there will be large departures from this average at individual locations.

Little information was obtained at Nottingham regarding the effect of mixed polarisation on reception in the home with portable receivers. Such information as there was is consistent with the results obtained from the earlier Kingswood tests, i.e. that this type of reception is substantially unaffected by the change.

The foregoing is concerned only with the magnitude of the signal. The investigation of the effects of multipath propagation on any change of polarisation did not produce a conclusive result although there was some evidence that the r.c.p. transmission was slightly more susceptible to disturbance than was h.p.

On balance, it appears that a change to mixed polarisation for Band II transmissions would confer a quite substantial benefit to users of car radio and portable receivers outdoors at the expense of a smaller disadvantage to listeners at home using efficient aerials at roof height. The advantage for this latter class of listeners of slant over circular polarisation would be more apparent than real unless all Band II

transmitters serving a given area were co-sited and used the same type of polarisation.

There seems little to choose between the various types of mixed polarisation on grounds of performance. If a decision to adopt mixed polarisation were made, the type used could well be determined by the economics of the aerial and feeder installation required at the transmitter.

8. References

1. Band II f.m. sound broadcasting: the effects of a change to circular polarization. BBC Research Department Report No. 1969/7.
2. Standards on Wave Propagation: Definitions of Terms, 1950, *Proc. Inst. Radio Engrs*, 1950, 38, 11, pp. 1264–1267.
3. V.H.F./F.M. Multipath Propagation Test Set, *Wireless Wld*, 1959, 65, 11, pp. 559–562.
4. Field strength near the ground at v.h.f. and u.h.f.: theoretical dependence on polarization. BBC Research Department Report No. 1969/3.

9. APPENDIX:

*The relative phase of the h.p. and v.p. components**

If a horizontal aerial, or a vertical aerial, is used for reception of a transmission with mixed polarisation, the relative phase of the h.p. and v.p. components of the incident wave has no effect on the strength of the received signal. If an inclined aerial is used, however, a change in the relative phase of the two components will in general modify the resultant input to the receiver. Thus if slant polarisation is transmitted and the relative phase of the two components subsequently changes by an angle ϕ , elliptical polarisation with the same slant angle results and the voltage induced in an inclined aerial is reduced by a factor of $\cos(\phi/2)$.

The object of this Appendix is to examine the extent to which the relative phase may change on an idealised propagation path, i.e. over perfectly flat ground, and to consider whether the effect was significant at Nottingham.

The relative amplitude of the two resultant components after ground reflection has been discussed in an earlier report.⁴ Fig. 2, which is taken from this report, is a vector diagram which shows the relationship between these two components, assuming that the h.p. and v.p. incident waves are equal and co-phased. (Over the range of angles of incidence of interest, the difference in phase of the reflection coefficients is very small and is neglected in Fig. 2).

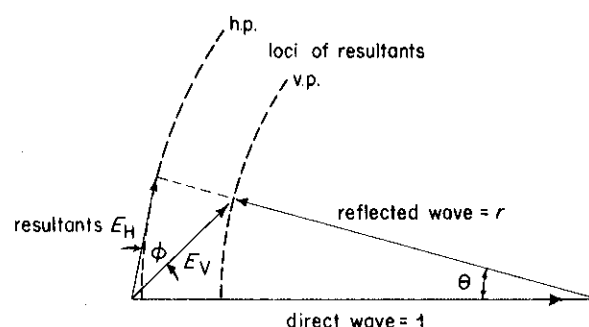


Fig. 2 — Vector diagram showing phase angle between h.p. and v.p. components

* This Appendix was contributed by P. Knight

It will be seen that the vertical component E_v is retarded, relative to the horizontal component E_H , by an angle ϕ . The value of ϕ depends on θ , which is the retardation suffered by both reflected waves due to the greater distance which they travel.

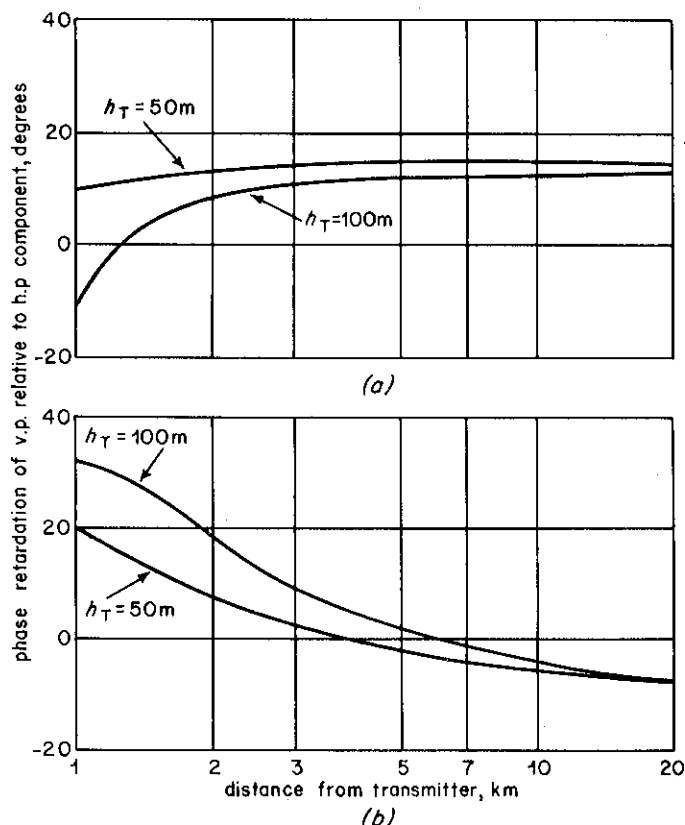


Fig. 3 — Phase shift of v.p. relative to h.p. component of signal received at 10 m a.g.l.

(a) due solely to ground reflection

(b) taking v.p./h.p. aerial separation into account

h_T = effective height of transmitting aerial above mean terrain level

Although ϕ may be quite large when θ is small, this situation arises only near the ground and is of little practical interest. Calculations show that ϕ is small at roof level, where inclined aerials would

normally be mounted. This may be seen from Fig. 3(a), which shows how ϕ would vary at 10 m a.g.l. over ground having a dielectric constant of 20, under ideal conditions. Curves are shown for transmitting aerial heights of 50 and 100 m, since these are typical of the effective heights of the Nottingham aerial above mean terrain level, in various directions.

The curves of Fig. 3(a) would apply if the transmitting aerial were specially designed to radiate a prescribed form of mixed polarisation. This was not the case at Nottingham, where a vertical aerial was mounted 6 m above the centre of an existing horizontal aerial, and the relative phase of the aerial feeds was adjusted to obtain the required polarisation after reflection in the ground, at a test receiving site.

The effect of mounting the vertical aerial at a greater height was to add a further phase retardation to the vertical component. This additional retardation was greatest at short distances; at 1 km, for example, it was 68° in the directions in which the effective height of the transmitting aerial is 100 m.

Adjustment of the relative phase of the feeds to the two aerials completely eliminated both phase retardations at the test site, and left a residual phase difference at other sites. Fig. 3(b) shows the phase difference which remained, again assuming ideal conditions. Curves are shown for effective transmitting aerial heights of 50 m and 100 m as before. The effective height for the direction of the test site was 100 m, and it will be seen that the residual phase at the distance of this site (6.2 km) is zero. Fig. 3(b) shows that the residual phase at distances greater than 3 km was less than 10° .

With slant polarisation a phase shift of 10° would reduce the voltage induced in a correctly-oriented receiving aerial by less than 0.1 dB. If the aerial were rotated in the vertical plane the ratio of the maximum to minimum induced voltages would be equal to the axial ratio of the polarisation ellipse and would be 21 dB for a phase shift of 10° .